DEPARTMENT
OF
MECHANICAL ENGINEERING

N67 11699
(ACCESSION NUMBER)

(THRU)

57
(PAGES)

1
(CODE)

CR 79540
(NASA CR OR TMX OR AD NUMBER)

33
(CATEGORY)

FACILITY FORM 602

Quarterly Progress Report #1, NAS8-20284
VIBRATION EFFECTS ON HEAT TRANSFER
IN CRYOGENIC SYSTEMS

June 1, 1966 - August 31, 1966

GPO PRICE $ ____

CFSTI PRICE(S) $ ____

Hard copy (HC) 3.00

Microfiche (MF) .50

ff 653 July 65

ENGINEERING AND
INDUSTRIAL RESEARCH STATION

MISSISSIPPI STATE UNIVERSITY
STATE COLLEGE, MISSISSIPPI

Department of Mechanical Engineering
Mississippi State University
State College, Mississippi 39762

Quarterly Progress Report #1, NAS8-20284
VIBRATION EFFECTS ON HEAT TRANSFER IN CRYOGENIC SYSTEMS

Period Covered: June 1, 1966 - August 31, 1966

By

E. H. Bishop, Associate Professor
C. J. Bell, Associate Professor
C. T. Carley, Associate Professor
R. E. Forbes, Graduate Assistant
E. W. Wellborn, Graduate Assistant
E. W. Farrar, Graduate Assistant

Quarterly Progress Report:
Contract Number: NAS8-20284

This report was prepared by Mississippi State University under Contract NAS8-20284, Vibration Effects on Heat Transfer In Cryogenic Systems, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory of the George C. Marshall Space Flight Center with Mr. Hugh M. Campbell acting as project manager.

TABLE OF CONTENTS

LIST OF FIGURES

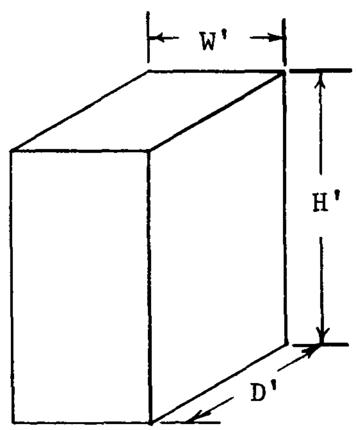
NOMENCLATURE

A	$(=H'/W')$ Aspect ratio
a'	Maximum amplitude of vibration
B'	Body force
c'	Specific heat
D'	Enclosure depth (see sketch below)
g'	$(=a'\omega'^2)$ Maximum enclosure acceleration
g_o'	Acceleration of gravity
H'	Enclosure height (see sketch below)
k'	Thermal conductivity
P'	Pressure
Pr	$(=\mu'c'/k')$ Prandtl number-dimensionless
Ra	$(=(T_h'-T_c')\overline{\beta}W'^3g/\alpha'\nu')$ Rayleigh number-dimensionless
T'	Temperature
T	$(=[T-T_c']/[T_h'-T_c'])$ Dimensionless temperature
t'	Time
t	$(=\nu't'/W'^2)$ Dimensionless time
u'	x'-component of velocity
v'	y'-component of velocity
V'	Enclosure motion
V	$(=V'/a'\omega')$ Dimensionless enclosure motion
W'	Enclosure width (see sketch below)
x'	Cartesian coordinate (see Fig. 1)

x	$(=x'/W')$ Dimensionless coordinate
y'	Cartesian coordinate (see Fig. 1)
y	$(=y'/W')$ Dimensionless coordinate
α'	Thermal diffusivity
β'	Volumetric coefficient of thermal expansion
μ'	dynamic viscosity
ν'	$(=\mu'/\bar{\rho}')$ Kinematic viscosity
ρ'	Density
ψ'	Stream function
ψ	$(=\psi'/\alpha')$ dimensionless stream function
ω'	Frequency

Subscripts

c	Vertical boundary at $x' = W'$
h	Vertical Boundary at $x' = 0$
p	Constant pressure
v	Constant volume
y	y direction



INTRODUCTION

This is the first Quarterly progress Report for NAS8-20284, VIBRATION EFFECTS ON HEAT TRANSFER IN CRYOGENIC SYSTEMS. The period covered is June 1, 1966 to August 31, 1966.

N67-11699 This report presents the results of an intensive search of the literature for published research on natural convection within enclosures, the effects of vibration on natural convection, and the effects of vibration on fluid transport properties (thermal conductivity and viscosity). The governing equations for the initial geometrical configuration for the natural convection study are formulated in dimensionless form and disucssed, and the final initial design of the companion experimental system is presented and discussed. A brief general discussion of the transport-property study is given. Author

ANALYSIS OF PROGRESS

The literature survey has been completed, and 225 articles have been catalogued as being of possible interest to this research. A number of these articles, which were considered most pertinent to the specific problem being investigated, were abstracted for quick reference to their content. The survey of the literature yielded a very comprehensive working bibliography covering natural convection, the effects of vibration on natural convection, and transport property determination.

An initial mathematical formulation of the following problem has been completed:

> Consider the laminar two-dimensional natural convection of a fluid enclosed between two plane vertical boundaries, which are held at different temperatures, with the space between them closed by horizontal boundaries. In the remaining direction the space is considered to extend to infinity. The enclosure, formed as described above, is subjected to either longitudinal or transverse vibration.

A set of dimensionless differential equations and appropriate boundary conditions were obtained which showed that the dimensionless parameters Pr, Ra, H'/W', and g'/g_o' are sufficient to determine uniquely distributions of the stream function and temperature. The above results predict that experimentally determined heat transfer rates are correlatable by

$$Nu = F(Pr, Ra, H'/W', g'/g_o').$$

A preliminary design of an apparatus to study experimentally the natural convection problem described in the previous paragraph has been completed. Considering force limitations of the vibration testing system, acceleration and aspect ratio limits have been established. From all possible configurations within these limits two height-depth combinations were chosen which, using three or more side plate widths each, will allow aspect ratios from 1 to 31 to be achieved. Methods have been selected for heating, cooling, temperature measurement, velocity measurement and flow visualization. Test cell final design has been started using the guidelines above. Also, a dummy cell has been designed which is to yield information concerning induced lateral accelerations and mounting plate integrity. This information, which will be available shortly, will be of use during the final design period.

The molecular theories of liquids which appear in the literature have been studied for the purpose of selecting one theory from among those which have been proposed to use as a basis for an analytical attack on the problem of the effect of vibrations on transport properties of liquids.

PROGRESS

Literature Search

A literature search was made to obtain the reported research in the following areas: (a) natural convection within enclosures, (b) the effects of vibration on natural convection (both for simple shapes vibrating in an infinite atmosphere and vibrating enclosures completely or partially filled with a fluid), (c) transport property determination (both theoretical and experimental), and (d) the effects of vibration on the thermal conductivity and viscosity. The search included the following sources of information:

1. Engineering Index
2. Applied Mechanics reviews
3. Dissertation Abstracts
4. Heat Transfer Bibliography (appears periodically in International Journal of Heat Mass Transfer)

5. Chemical Abstracts

6. Science Abstracts

Appendix I is a listing of the articles located which are presented under two major categories; (a) natural convection in enclosures and the effects of vibration on natural convection and (b) transport property determination and the effects of vibrations on properties. Many of the articles have been abstracted to show the relevance of a particular article to the research problem and to serve as a reminder to the research team of the content of particular papers. Those articles not abstracted were considered to be of peripheral interest, however, each of these articles was reviewed by at least one member of the research group. It should be emphasized that Appendix I is to serve as a working bibliography, and new articles will be added as they appear or as the research proceeds and new emphasis occurs.

The Natural Convection Problem and Its Formulation

Consider the laminar two-dimensional natural convection of a fluid enclosed between two plane parallel vertical boundaries a distance W' apart which are held at different temperatures. The space between the vertical boundaries is closed by two horizontal boundaries a distance H' apart where $H' >> W'$ (see Fig.1). In the remaining direction, at right angles to the plane of the sketch in Fig. 1, the space is considered to extend to infinity. The enclosure, formed as described above and depicted in Fig. 1, is subjected to either longitudinal or transverse vibration.

The problem is now formulated with respect to a moving co-ordinate system which is fixed to the vibrating enclosure. Under vibratory conditions, the enclosure and confined fluid are assumed to vibrate together as a bulk, i. e., no relative motion exists between the enclosure walls and the confined liquid as a result of the vibration.

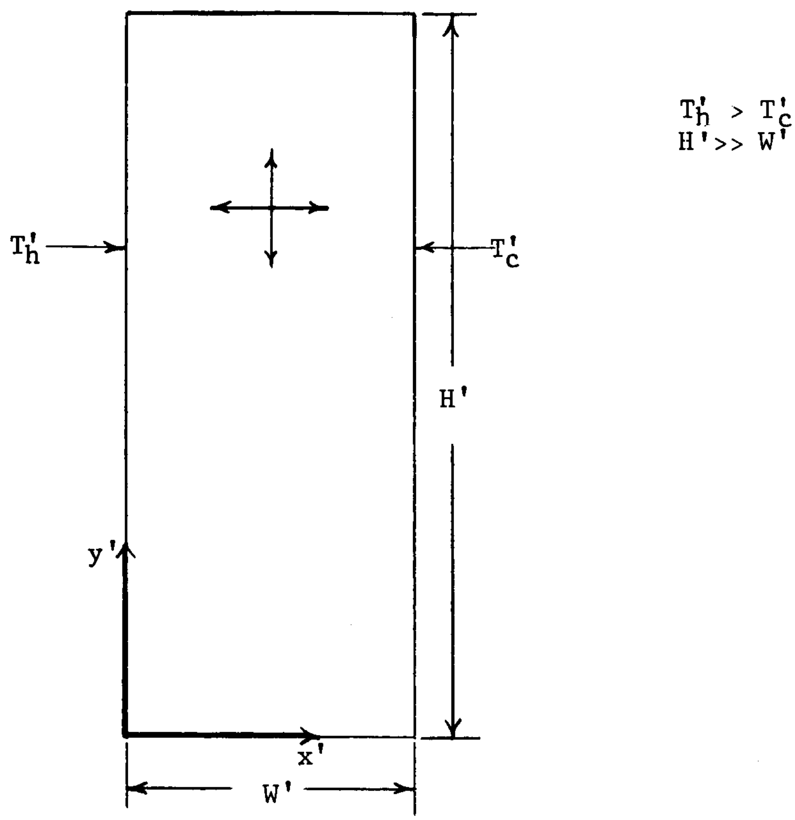


Figure 1. Schematic Diagram of Rectangular Enclosure Subjected to Either Transverse or Longitudinal Oscillations.

This assumption is crucial in that the mathematical formulation of the problem depends in large measure upon how the vibration effects are incorporated into the momentum equations. Additional assumptions relating to the manner in which density variations are considered are also required, and these assumptions must be weighed quite carefully in the final analysis. Each of the aforementioned assumptions will be discussed and justified at the point in the development where it is made.

Let T_h' and T_c' be the temperatures of the left and right vertical boundaries respectively. (All dimensional quantities are primed and all dimensionless quantities are unprimed.) Since pressure differences in the fluid will be small in comparison to the absolute pressure, variations in density will be determined by variations in the temperature T'. If the ratio $(T_h' - T_c')/T_h'$ is small, variation in the temperature of the fluid normally needs to be considered only in the determination of the buoyancy force. However, since there is an added force in the momentum equations due to the enclosure motion, which involves the density of the fluid, and since it is of primary importance to determine the coupling of these two forces, variations in the density will also be considered in this added d'Alembert force. In the other force terms of the momentum equations the density will be considered uniform at its mean value, i.e., its value at $\bar{T} = (T_h' + T_c')/2$.

Considering the assumptions described above, the equation of conservation of mass is

$$\frac{\partial u'}{\partial x'} + \frac{\partial v'}{\partial y'} = 0 \tag{1}$$

where x', y' are the coordinates as shown in Fig. 1 and the corresponding velocities are u', v'.

Assuming no temperature change in the fluid due to compression and/or viscous dissipation, the energy equation becomes

$$\frac{DT'}{Dt'} = \alpha' \nabla^2 T' \quad . \tag{2}$$

In equation (2) $\frac{D}{Dt'}$ is the substantial derivative and ∇^2 is the Laplacian operator and are given by

$$\frac{D}{Dt'} = \frac{\partial}{\partial t'} + u' \frac{\partial}{\partial x'} + v' \frac{\partial}{\partial y'}$$

$$\nabla^2 = \frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial y'^2} \quad , \text{ and}$$

t' is time and α' is the thermal diffusivity ($k'/\bar{\rho}'c_p'$ for gases, $k'/\bar{\rho}'c_v'$ for liquids where $\bar{\rho}'$ is the density evaluated at $\bar{T}'$, k' is the thermal conductivity of the fluid and c_p', c_v' are the specific heats); α' is considered uniform at its value at $\bar{T}'$.

Considering transverse vibration (x'direction) the momentum equations are:

$$\frac{Du'}{Dt'} = - \frac{1}{\bar{\rho}'} \frac{\partial P'}{\partial x'} + \nu' \nabla^2 u' - \frac{\rho'}{\bar{\rho}'} \frac{dV'}{dt'} \tag{3}$$

$$\frac{Dv'}{Dt'} = - \frac{1}{\bar{\rho}'} \frac{\partial P'}{\partial y'} + \nu' \nabla^2 v' + \frac{B_y'}{\bar{\rho}'} \tag{4}$$

where P' is the pressure in the fluid, ν' is the kinematic viscosity $(=\frac{\mu'}{\rho'})$, V' is the enclosure motion, and B_y' is the body force. B_y' is equal to $-\rho' g_o'$ which, considering the previous assumption regarding the smallness of $(T_h' - T_c')/T_h'$, may be written

$$B_y' = -\bar{\rho}' g_o' \bar{\beta}' T' + C \qquad (5)$$

where $\bar{\beta}'$ is the volumetric coefficient of thermal expansion, g_o' is the acceleration of gravity, and C is a constant which is of no significance in that it falls out of the final equations. The enclosure motion is assumed sinusoidal so that

$$V' = a'\omega' \cos \omega' t' \qquad (6)$$

where a' and ω' are the amplitude and frequency of vibration respectively. The last term in equation (3) is a 'so-called' d'Alembert force which arises from the vibration of the enclosure and the assumption that the enclosure and confined fluid move as a bulk.

The boundary conditions that will be placed on the variables u', v', and T' at the vertical boundaries are

$$u' = v' = 0, \quad T' = T_h', \text{ at } x' = 0$$
$$u' = v' = 0, \quad T' = T_c', \text{ at } x = W'.$$

The governing equations may be simplified by writing them in dimensionless form and introducing the stream function which satisfies the continuity equation identically. We define the following dimensionless variables:

$$\psi = \psi'/\alpha' \text{ where } u' = \frac{\partial \Psi'}{\partial y'} \text{ and } v' = -\frac{\partial \Psi}{\partial x'}$$

$$T = \frac{T' - T'_c}{T'_h - T'_c}, \quad V = \frac{V'}{a'\omega'}, \quad t = \frac{\nu' t'}{W'^2}$$

$$x = \frac{x'}{W'}, \text{ and } y = \frac{y'}{W'}.$$

The energy equation (2) can now be written as

$$\frac{\partial T}{\partial t} + \frac{1}{Pr}\frac{\partial(T,\Psi)}{\partial(x,y)} = \frac{1}{Pr}\nabla^2 T \tag{7}$$

where $\dfrac{\partial(T,\Psi)}{\partial(x,y)} \equiv \dfrac{\partial T}{\partial x}\dfrac{\partial \Psi}{\partial y} - \dfrac{\partial T}{\partial y}\dfrac{\partial \Psi}{\partial x}$

and Pr is the Prandtl number $(= \frac{\mu' c'}{k'})$. The pressure is now eliminated from equations (3) and (4), ρ' is eliminated with the use of equation (5) and equation (6) is used in writing the d'Alembert force. These operations give

$$\frac{\partial(\nabla^2\Psi)}{\partial t} + \frac{1}{Pr}\left\{\frac{\partial(\nabla^2\Psi, \Psi)}{\partial(x,y)}\right\} = \nabla^2 (\nabla^2\Psi) - Ra\left\{\frac{\partial T}{\partial x} + \frac{g'}{g'_o}\sin\frac{\omega' W'^2 t}{\nu'}\frac{\partial T}{\partial y}\right\} \tag{8}$$

where Ra is the Raleigh number $= \frac{(T'_h - T'_c)\bar{\beta} W'^3 g}{\alpha' \nu'}$ and $g' = a'\omega'^2$ is the maximum acceleration of the enclosure.

The boundary conditions are now

$$\Psi(o,y,t) = \frac{\partial\Psi(o,y,t)}{\partial x} = 0 \qquad \Psi(1,y,t) = \frac{\partial\Psi(1,y,t)}{\partial x} = 0$$

$$\Psi(x,o,t) = \frac{\partial\Psi(x,o,t)}{\partial y} = 0, \qquad \Psi(x,H'/W',t) = \frac{\partial\Psi(x,H'/W',t)}{\partial y} = 0,$$

$$\Psi(x,y,o) = o, \; T(x,y,o) = T_o \text{ (initial uniform temperature)},$$

$$T(o,y,t) = 1, \; T(1,y,t) = 0, \qquad \frac{\partial T(x,o,t)}{\partial y} = \frac{\partial T(x,H'/W',t)}{\partial y} = 0.$$

For longitudinal vibrations, y' direction, equation (8) needs only to be modified by changing the sign of the last term in braces on the right-hand side to minus and the $\frac{\partial T}{\partial y}$ to $\frac{\partial T}{\partial x}$. The remaining equations are unaltered.

The form of the governing equations (7) and (8) and the above boundary conditions show that the following dimensionless parameters are sufficient to determine uniquely the Ψ and T distributions: Pr, Ra, H'/W', and g'/g'_o. The first three parameters would appear for the same problem without vibration, and thus, this mathematical formulation shows that there is only one additional parameter required for the vibration problem, the acceleration ratio g'/g'_o.

From the previous discussion we see that it should be possible to express experimental heat transfer results in the following functional form:

$$Nu = F(Pr,\ Ra,\ H'/W',\ g'/g'_o) \tag{9}$$

where Nu is an appropriately defined Nusselt number encompassing measured heat transfer rates.

Experimental System

The initial experimental effort is to be directed toward collecting data using water as the test cell fluid. This cell will be vibrated both transversly and longitudinally, will be heated on one side by an electrical heater and cooled on the other, and will be constructed to allow flow visualization and temperature distribution measurements.

The University's 2000 pound force vibration laboratory (Unholtz-Dickie) has been readied for use on this project. The spaces have been cleared, air-conditioning installed, and instrumentation is being readied or has been ordered.

Test Cell Design

In the adopted nomenclature for the enclosure, an investigation has been made into the ranges of H'/W' and D'/W' which can be used. The limiting factors in the selection of test cell sizes were the test cell weight and the provision of sufficient cell depth to guarantee two-dimensionality. In order to reach the 25 g acceleration level with the vibration system to be used, a total table load of 60 pounds must not be exceeded. This total weight will consist of the heat source and sink plates, the base plate, the test fluid, and any instrumentation which must be placed on the cell. Another design objective was to study cells with aspect ratios (H'/W') from 1 to as high as 40. In order to provide as many aspect ratio configurations as possible, computer calculations were made on the size ranges available under the following assumptions.

(1) Total cell weight of 40 pounds

(2) One-inch thick heater, guard heater and cold plates. Assumed to be solid aluminum.

(3) Vary H' from 2 to 24 inches in increments of 2 inches

(4) For each H' vary W' from 1 to 30 inches in increments of 1 inch.

With these restrictive limits the ranges in available values of D'/W', H'/W' and maximum W' were calculated. Those having a D'/W' ratio of 5 or greater were assumed to satisfy two-dimensionality requirements. The cells with configurations as described are shown in Appendix 1. From these sizes two cell height-depth combinations were chosen. For each of these combinations the cell width will be varied to provide different configurations with the characteristics shown below.

Height - 16"; Depth - 7"
Using 3 sets of sideplates

W'	H'/W'	D'/W'
1.7	9.3	4.1
1.0	15.8	7.0
0.5	31.0	14.0

Height - 4"; Depth - 22"
Using 4 sets of sideplates

W'	H'/W'	D'/W'
4.0	1.0	5.5
2.0	2.0	11.0
1.0	4.0	22.0
0.5	8.0	44.0

As shown, the construction of two sets of hot and cold plates, using several sets of sideplates for each, will allow testing of a range of aspect ratios from 1 to 31. Construction and use of the 7" x 16" set of hot and cold plates will preceed the construction of the 4" x 22" set. The experience of design and operation of the first cell will allow improvements in the second.

Hot, cold, and guard heater plates are to be constructed of aluminum. Hot plates and guard heaters will make use of strip heaters while the cold plate will be integrated into the evaporator circuit of a refrigeration system. All plates are to be instrumented with thermocouples in sufficient number to monitor and control the thermal environment of the cell.

Consideration, with supporting calculations, was given to electroplating the plate surfaces to provide a more uniform thermal field. The techniques of electroplating aluminum with copper or silver were such that no improvement in the thermal uniformity of the plates could be expected.

Temperature Measurements

The temperatures of the fluid enclosure will be measured with thermocouples imbedded in the plates. After considering several methods of measuring temperature distributions in the fluid, the following method was chosen. The factor in this selection carrying the most weight was to reduce the stirring action of any type of thermal probe during cell vibration. The optimum solution consisted of suspending butt-welded thermocouples horizontally across the width of the cell. These thermocouples will be mounted so that they may be moved axially thus causing the junction to traverse the width of the cell. Several thermocouples of this type will be installed across the cell. A calculation was made to estimate the maximum center displacement of a thermocouple wire suspended in the above manner. The calculation indicated that a small amount of tension will be necessary in the wire in order to render this displacement negigible. The tension is to be produced by use of small spring mounts for each thermocouple.

Flow Visualization

Several methods of flow visualization have been reviewed and studied. One stands out in its simplicity, ease of application, and ability to yield quantitative, as well as qualitative, results. This method was described by Brooks(181a)in his thesis. It makes use of small (average size-100 microns) neutrally bouyant particles, a high intensity light source, and photographic recording equipment. The spherical shape of the particles (Eccospheres-by Emerson and Cuming, Inc.) causes them to reflect and refract light readily. The use of an interrupted light source will show the motion of the particles as traces on a photographic plate. These traces can be correlated with the frequency of light source interruption to yield velocity data. Brooks has shown that particle densities as low as 0.0083 grams/ft^3 of water are sufficient for utilization of this method; thus, no appreciable effect is expected on the motion of the fluid.

A generous supply of these particles has been ordered and the selection process is underway to obtain a satisfactory light source.

Design Considerations

A dummy cell, to be constructed of aluminum, has been designed to simulate the mass distribution of a typical test cell. This unit is to be instrumented with accelerometers to determine the extent of transverse vibration induced from point to point on the cell by vertical vibration of the shaker table.

This dummy unit should provide valuable information quickly on the integrity of any mounting plate designs. It will also yield estimations of the several possible modes of resonance of the test cell unit.

Considerable thought has gone into the problem of avoiding the presence of bubble coalescence. The use of distilled, filtered, and de-gassed water is anticipated. Details of the cell design are also being incorporated to eliminate any free surface and bubbles from the cell liquid.

Consideration is also being given to the possible effects of the magnetic field from the shaker on thermocouples and other instrumentation.

Transport Properties

The analytical study of the effect of vibrations upon the transport properties of liquids is being undertaken from the molecular (or kinetic theory) viewpoint. Since a complete and widely accepted kinetic theory of liquids has not yet been formulated, several of the semi-empirical, approximate theories have been considered for application in this study.

The theory of Born and Green (185) is a mathematical formulation of a general kinetic theory which involves the use of a complete set of distribution functions rather than the single distribution function necessary in the kinetic theory of gases. The solution to the resulting equations is not yet known for most cases. Nevertheless, the theory of Born and Green is being considered as the basis for the study of the effect of vibrations on transport properties because of its completeness.

The theories of Eyring, Enskog and Kirkwood (204) have also been considered for this study.

In addition to selection of a theory of liquids as a basis for the analytical study, the question of the manner in which vibrational effects should be introduced into the equations has also been considered. Although no final decision has been reached on this aspect of the problem, it appears that the vibrational effects will be introduced as a sinusoidal force equally distributed among the molecules of the system.

PROGRESS EXPECTED DURING NEXT REPORT PERIOD

The mathematical formulation presented in this report is a first effort at obtaining the governing equations of natural convection of a fluid contained between two vertical isothermal boundaries subjected to either longitudinal or transverse oscillations. The use of a moving coordinate system, which simplifies the writing of boundary conditions, will be explored further to ensure that all the necessary terms have been included in the momentum equations. The assumptions used in the development of the final equations (7) and (8) will be re-evaluated to ensure appropriateness and validity. Because of the complexity of the governing equations, and the lack of mathematical techniques suitable to obtain closed-form solutions of the complete equations, attempts will be made to simplify these equations to a tractable form.

Experimental work planned for accomplishment during the next reporting period will consist primarily of constructing and instrumenting a test cell. Once completed, the cell will be operated in the stationary mode and the resulting data compared with published information for natural convection in enclosures. This comparison will prove the integrity of the test cell and instrumentation configuration. With this work completed during the forthcoming report period the investigation of performance under vibration can be started in the subsequent period.

The study of the various molecular theories of liquids will be continued with the goal being the final selection of one of these theories as the basis for the study of the effects of vibrations upon the transport properties.

The criteria for final selection of a suitable theory will include: the mathematical tractability of the resulting equations, the feasibility of including an external force in the equations, and the numerical results that have been obtainable from previous applications of the theory.

APPENDIX I

BIBLIOGRAPHY

NATURAL CONVECTION IN ENCLOSURES AND THE EFFECTS OF VIBRATION ON NATURAL CONVECTION

1. ABBOT, M. R., "A Numerical Method for Solving the Equations of Natural Convection in a Narrow Concentric Cylindrical Annulus with a Horizontal Axis," Quarterly Journal of Mechanics and Applied Mathematics, 17, pp. 471-481 (1964).

   A numerical method is given for solving the equations of steady laminar natural convection in a narrow concentric cylindrical annulus with a horizontal axis. Method restricted to narrow, i.e., small gap thickness, cylindrical annuli.

2. ANANTANARAYANANR. and A. RAMACHANDRAN, "Effect of Vibration on Heat Transfer from a Wire to Air in Parallel Flow," Trans. ASME, 80, p. 1426 (1958).

   This paper presents the results of an experimental investigation of the influence of vibration on heat transfer from an electrically heated nichrome wire to parallel air streams. Both frequency and amplitude increased the heat-transfer rate, in some cases up to an increase of 130%. A correlation equation is presented.

3. ANDRES, J. M. and U. INGARD, "Acoustical Streaming at Low Reynolds Numbers," Journal of the Acoustic Society of America, 25, no. 5, pp. 932-938 (Sept. 1953).

4. ANDRES, J. M. and U. INGARD, "Acoustical Streaming at High Reynolds Numbers," Journal of the Acoustic Society of America, 25, no. 5, pp. 923-932 (Sept. 1953).

5. ARPACI, V. S.,J. A. CLARK and S. ESHGHY, "The Effect of Longitudinal Oscillations on Free Convection from Vertical Surfaces," ASME Trans., Series J. of Appl. Mechanics, 32, pp. 183-191 (March, 1965).

   This is a solution for the heat transfer from a vertical surface in an infinite incompressible fluid in laminar flow being vibrated in its own plane (vertically). The solution is achieved through solution of the boundary layer equations by linearization to yield two simpler equations. Two solutions are offered; one for small frequencies by complex integration and another for large frequencies by assuming velocity and temperature profiles (Von Karman Integral technique). The results predict first a decreasing and then an increasing heat transfer coefficient as the velocity amplitude of vibration is increased. This result was verified by experiment using a vertical cylinder.

6. ASATURYAN, A. S. and B. A. TONKOSHKUROV, "Free Thermal Convection near the Linear Source of Heat," AD 610 372.

The authors consider the case of a horizontal cylinder in an infinite atmosphere. They use the boundary layer equations (questionable) and solve them using the Karman Polhausen Integral techniques. Then drawing on experiments for the limits of integration they find

$$Nu = 0.839\ (Gr\ Pr)^{1/4}$$

There follows an experiment using nichrome wires in two oils which results in

$$Nu = 0.882\ (Gr\ Pr)^{1/4}$$

Extensive comparison of coefficients is made with previous results.

7. BARAKAT, H.Z., "Transient Laminar Free-convection Heat and Mass Transfer in Two-dimensional Closed Containers Containing Distributed Heat Source," ASME Paper 65-WA/HT-28.

This paper makes use of finite difference techniques to determine temperature and velocity distributions in a two-dimensional rectangular container filled with a heat generating fluid. The method also allows a qualitative estimation of the transient effects. Comparison is made with the experimental results of other authors.

8. BATCHELOR, G. K., "Heat Convection and Buoyancy Effects in Fluids," Quarterly Journal Roy. Meteor Soc., **80**, no. 345, pp. 339-348, 1 plate (July 1954).

9. BATCHELOR, G. K., "Heat Transfer by Free Convection Across a Closed Cavity Between Vertical Boundaries at Different Temperatures," Quart. of Applied Mathematics, **12**, pp. 209-233 (1954).

This paper presents a theoretical analysis of the two-dimensional convective motion generated by buoyancy forces on the fluid in a long rectangle, of which the two long sides are vertical boundaries held at different temperatures. No closed form analytic solution is obtained, however certain conclusions concerning when the effect of convection is negligible one made based upon fractional analysis of the governing equations.

10. BECK, J. V., "Calculation of Thermal Diffusivity from Temperature Measurements," J. Heat Transfer, **85**, no. 2, p. 181 (1963).

11. BECKMAN, W., "Die Warmeubertrangung in Zylindrischen Gasschichten Bei Naturlicher Konvektion," Forsh Geb. Ingenieurn, **2**, pp. 165-178, 212-227, 407 (1931).

12. BERGLES A. E. and P. H. NEWELL, JR., "The Influence of Ultrasonic Vibrations on Heat Transfer to Water Flowing in Annuli," Int. J. Heat and Mass Transfer, 8, no. 10, pp. 1273-1280 (1965).

This paper reports the results of an experimental study of the effects of high-intensity ultrasonic vibrations on heat transfer to water flowing in annuli. The inner tube was electrically heated. Heat transfer was improved with vibration; vapor reduced the effect of vibration.

13. BINDER, R. C., "The Damping of Large Amplitude Vibrations of a Fluid in a Pipe," Jour. of the Acoustical Soc. of America, 15, pp. 41-43 (1943).

14. BIRD, R. B., "Berekeningsmethoden Voor Het Warmtegeleidingsvermogen Van Gassen En Vloeistoffen," Ingenieur, 70, no. 35, pp. 57-62 (Aug 29,1958).

15. BISHOP, E. H., L. R. MACK and J. A. SCANLAN, "Heat Transfer by Natural Convection Between Concentric Spheres," submitted to International J. of Heat and Mass Transfer, 1965.

An experimental investigation is described concerning natural convection of air enclosed between two isothermal concentric spheres of various diameter ratios. Measured temperature profiles are analyzed in detail. The profiles are explained in terms of the flow patterns observed in the visual study. An emperical equation is presented that correlates the measured heat transfer rates to within 15%.

16. BISHOP, E. H., R. S. KOLFLAT, L. R. MACK and J. A. SCANLAN, "Convective Heat Transfer Between Concentric Spheres," Proc. 1964 Heat Transfer Fluid Mech. Inst., pp. 69-80, Standford Univ. Press (1964).

This paper presents the result of a study of the flow patterns and temperature distributions occuring between two concentric isothermal spheres of various diameter ratios with air in the intervening space. Qualitative descriptions and photographs of the flow patterns are given and temperature distributions are correlated with these patterns.

17. BISHOP, E. H., R. S. KOLFLAT, L. R. MACK, and J. A. SCANLAN, "Photographic Studies of Convection Patterns between Concentric Spheres," Soc. Photo-optical Instr. Engngrs. J., 3, pp. 47-49 (1964-1965).

18. BJORKLUND, I. S., and W. M. KAYS, Trans. ASME J. Heat Transfer, 81, Series C, 175 (1959). Concerns heat convection in air enclosed by two rotating cylinders.

19. BLANKENSHIP, V. D., "The Influence of Transverse Harmonic Oscillations on the Heat Transfer from Finite and Infinite Vertical Plates in Free Convection," PhD thesis Univ. of Michigan, Ann Arbor (August 1962).

20. BLANKENSHIP, V. D. and J. A. CLARK, "Experimental Effects of Transverse Oscillations on Free Convection of a Vertical, Finite Plate," Trans. Amer. Soc. Mech. Engrs. Series C, Journal of Heat Transfer, 86, 2, pp. 159-165 (May 1964).

The authors present an analytical solution to the problem of predicting the effects of transverse oscillation on free convection from a vertical finite plate. The Formulation of the problem assumes that the bouyancy effects predominate, the fluid is incompressible, the bulk fluid moves as a mass, and that the normal boundary layer assumptions are appropriate for this problem. They consider that the effects of the effects of oscillations result mainly from an oscillating potential flow at the outer edge of the boundary layer. The method of solution employs a pertubation technique where the flow is considered to be principally nonvibratory free convection with velocity oscillations imposed as perturbations. The zeroth order approximation is taken as Ostrach's solution to the same problem without oscillations. The solution predicts a small decrease in the heat transfer rate for laminar flow. This conclusion was confirmed by experiment.

21. BLANKENSHIP, V. D. and J. A. CLARK, "Effects of Oscillation from a Vertical, Finite Plate," Trans. Amer. Soc. Engngrs., Series C, J. of Heat Transfer, 86, no. 2, pp. 149-158 (May, 1964).

This paper presents the results of experiments performed to confirm the conclusions reached analytically and reported in another paper. For laminar flow it was found that there was a negligible small reduction in the heat transfer rate as was predicted analytically. In addition, smoke traces indicated that for certain oscillation frequencies and amplitudes there was an early transition from laminar to turbulent flow with accompanying increases in the heat transfer rate. There is some question as to the accuracy of the experimental apparatus in obtaining true transverse oscillations of the plate. It appears that the method used to connect the plate to the exciter could permit a considerable amount of cross talk.

22. BOELTER, L. M. K. and W. E. MASON, "Vibration--its effect on Heat Transfer," Power Plant Engng., 44, pp. 43-46 (1940).

23. BOGGS, J. H. and W. L. SIBBITT, "Thermal Conductivity Meas. of Viscous Liquids," Indust. Engng. Chem., 47, 2, 289-293 (Feb. 1955).

24. BOLOTINA, K. S., "On Usloviyakh Vozniknoveniya Svobodnoi Knoveksii V Kanale Pryamougol'nogo Secheniyq," Akademiya Wauk SSSR, Izvestiya, Otdelenie Teknicheskikh Nauk, Mekhanika i Mashinostreonie, no. 1, pp. 73-6 (Jan-Feb 1962). (Conditions involving free convection in rectangular channel, asympotic solution presented for passage from molecular heat transfer to free convection in vertical rectangular channel.)

25. BORISOV, YU. YA. and YU. G. STATNIKOV, "Flow Currents Generated in an Acoustic Standing Wave," Jour. of Acoustics (USSR) Vol. 11, no. 1, (Jan-Mar 1965).

26. BUGAENKO, G. A., "Free Thermal Convection in Vertical Cylinders of Arbitrary Cross Sections," (in Russian) Pril. Mat. Mekh., 17, no. 4, pp. 496-500 (July-Aug. 1953).

27. BURDOKOV, A. P. and NAKORIZKOV, V. E., "Heat Transfer from a Cylinder in a Sound Field at Grashof numbers tending to Zero," Teploobmen at Tsilindra v Zvukovom Pole pri Priklandoi nekhaniki I Teknicheskoi Fiziki, pp. 119-124 (Jan/Feb. 1965). (in Russian)

28. BYKOV, L. T., "Estimation of the Rate of Displacement of Air in a Confined Space with Natural Convection," Jour. of Engineering Physics (Russian) 8, no. 2 (Feb. 1965).

29. BYKOV, L. T. and V. V. MALOZEMOV, "Some Temperature Distribution Relations for Confined Spaces with Internal Heat Sources," Jour. of Engr. Physics (Russian), 8, no. 2 (Feb. 1965).

30. CARLSON, W. O., "Interferometric Studies of Convective Flow Phenomena in Vertical Plane Enclosed Air Layers," PhD Thesis, Graduate School, Univ. of Minn. (1956).

31. CAVALLARO, L., A. INCELLI and G. PANCALDI, "On Some Improvements on a Cryoscopic Precision Apparatus and on the Control of a Thermocouple," (in Italian) Ric. Sci., 23, no. 12, pp. 2237-2243 (Dec. 1953).

32. CHANDRASEKHAR, S., Proc. Roy. Soc. (London) A237, p. 476 (1956). Free convection in thin layers heated from below.

33. CHERVIAKOV, S. S., "Experimental Investigation of the Influence of Vibration of a Sphere on Heat and Mass Exchange in a Turbulent Stream of Air," In Its J. of Eng. Phys. Misk, 6, no. 6, pp. 27034 (June 1963, 17 Dec. 1963). See N64-11965 03=01 OTS $3.50.

34. CHERVIAKOV, S. S., "Experimental Investigation of the Effect of Vibrations on the Heat and Mass Transfer of a Cylinder and a Cone in Turbulent Air Flow," Inzhenerno-Fizicheskii Zhurnal, 6, pp. 10-21 (Aug. 1963). (in Russian)

35. COULBERT, C. D., "Mach-Zehnder Interferometer Applications as Used in the Study of Convection and Conduction Heat-Transfer Systems," ASME Annual Meeting, New York, (Dec. 1952) Paper No. 52-A-9, 3 pp. 13 figs.

36. CRANDALL, I. B., "Theory of Vibrating Systems and Sound," D. Van Nostrand, Co., Inc., New York, pp. 95-103 and 229-241 (1927).

37. CRAWFORD, L. and R. LEMLICH, "Natural Convection in Horizontal Concentric Cylindrical Annuli," Industiral and Engng. Chemistry Fundamentals, 1, qp. 260-264 (1962).

The problem of steady, laminar natural convection between horizontal concentric cylinders was attacked numerically via finite difference approximations to the governing equations. The stream function and temperature distribution were obtained for several diameter ratios and Grashof numbers. No unstable flow conditions were obtained, but such conditions have been shown to exist by other researchers. An analytical solution is given for the creeping flow case, which is of little importance in most applications.

38. DE GRAFF, J. G. A. and E. F. M. VAN DER HELD, "The Realtion Between the Heat Transfer and the Convection Phenomena in Enclosed Plane Layers," Appl. Sci. Res. (A), 3, no. 6, pp. 393-409 (1953).

39. DEAVER, F. K., W. R. PENNEY, and T. B. JEFFERSON, "Heat Transfer from an Oscillating Horizontal Wire to Water," Trans. Amer. Soc. Mech. Engng. Series C, Journal of Heat transfer, 84, pp. 251-256 (1962).

A small horizontal wire in water was vibrated at low frequencies and relatively large amplitudes and the effects of this vibration on the heat flux were experimentally determined. It was concluded that either forced, free, or mixed convection correlations could be used to predict the heat transfer coefficient depending on the relative values of the Reynolds number and the Rayleigh number. The Reynolds number is based upon the mean velocity of the wire. In the mixed convection regime a correlation (conservative) was proposed.

40. DECKER, A. S., "Natural Convection Equipment," ASHRAE, J 7, no. 4, p. 45 (1965).

41. DONALDSON, I. G., "Free Convection in a Vertical Tube with a Linear Wall Temperature Gradient," Austral. J. Phys., 14, p. 529 (1961).

This paper presents a theoretical analysis of convection in a vertical tube closed at both ends in which the temperature of the walls is arranged to increase linearly with depth. An experimental study showed good agreement with theory up to a certain value of a modified Rayleigh number.

42. DOUGALL, R. S., T. CHIANG and R. M. FAND, "A study of the Differential Equations of Coupled Vibrations and Free Convection from a Heated Horizontal Cylinder," Wright-Patterson, AFB, Ohio, Aeronautical Research Lab, p. 24, 46, (Dec. 1961). refs. ARL-148 Part I.

43. DRAKHLIN, E., "On Heat Convection in a Spherical Cavity," (in Russian), Zh. Tekh. Fiz., 22, no. 5, pp. 829-831 (May 1952).

44. DROPKIN, D. and SOMERSCALES, E., "Heat Transfer by Natural Convection in Liquids Confined by Two Parallel Plates which are Inclined at Various Angles with Respect to the Horizontal," Journal of Heat Transfer C 87, pp. 77-84 (1965).

This paper is concerned with the effect of inclination on natural convection heat transfer in liquids confined by two parallel plates. Data is taken and mathematical relations are developed from which heat transfer coefficients can be determined. The fluids used were water, silicon oils, and mercury. One point of interest is that the authors considered the effect of aspect ratio negligible.

45. DUSINBERRE, G. M., "A Note On the Implicit Method for Finite-Difference Heat Transfer Calculations," ASME Trans., J. Heat transfer, Series C, pp. 94-95 (Feb. 1961).

This paper states that the advantage of the implicit method is the possibility of using large time intervals. However, after considering a particular problem it is concluded that the advantage of the larger time intervals may be outweighed by the loss of accuracy and the need for a longer computation time.

46. ECKART, C., "Vortices and Streams Caused by Sound Waves," The Physical Review, 73, no. 1, pp. 68-76 (Jan. 1, 1948).

47. ECKERT, E. R. G. and W. O. CARLSON, "Natural Convection in Air Layer Enclosed Between Two Vertical Plates with Different Temperatures," Inter. J. of Heat and Mass Transfer, 2, pp. 106-120 (1961).

Presents experimental technique, data, and correlations for parallel vertical flat plates using air. No vibration. Interferometry used to determine temperature profiles. Aspect ratios reported are 2.5, 10, 20 and 46.67. Relations for local and average heat transfer are given.

48. EICHHORN, R., "Flow Visualization and Velocity Meas. in Natural Conv. with Tellurium Die Method," ASME Trans., J. Heat Transfer, 83, Series C, pp. 379-381.

A technical brief which describes the use of tellurium probes to visualize the natural convective flows within various geometrical configurations. Requires an electrolyte solution.

49. EICHHORN, R., "Measurement of Low Speed Gas Flows by Partical Trajectories: A New Determination of Free Convection Velocity Profiles," Int. J. Heat Mass Transfer, 5, p. 915 (1962).

Concerns heat transfer data for a heated horizontal wire immersed in a water bath and oscillating in a vertical plane. This paper describes a technique of measuring air velocities in free convection flows using dust (zinc sterate) particles for tracers and photographic plates. The method agreed closely with the analytical solution except at points outside the maximum velocity area. Random air currents and very precise control of illumination make the method a tedious one.

50. ELDER, J. W., "Laminar Free convection in a Vertical Slot," J. Fluid Mech. 23, Pat. I, pp. 77-98 (1965).

This is an experimental study of the interaction of the shear and buoyancy forces in natural convection in a liquid. The experimental apparatus was a rectangular slot with two isothermal opposing sides at different temperatures. The experiments were run using medicinal paraffin and a silicone oil and were restricted to aspect ratios from 1 to 60 and Rayleigh numbers from 10 to 10^8.

The major emphasis in this report is placed on the uniform vertical temperature gradient found in the interior of the flow for Rayleigh numbers greater than 10^4 and the mechanics of the secondary flows.

51. ELDER, J. W., "Turbulent Free Convection in a Vertical Slot," J. Fluid Mech. 23, Part I, pp. 99-111 (1965).

An experimental study of unsteady and turbulent free convective flow in a vertical slot across which there is a uniform temperature difference. The aspect ratio was in the range 10-30, while the value of the Rayleigh number was greater than 10^6 . Using flow visualization techniques, the flow pattern in the slot was shown to consist of two trains of breaking waves,one travelling up the hot wall and one travelling down the cold wall, inducing a turbulent zone in the central portion of the interior. Within the interior of the slot, between the mixing regions near the walls, there existed a uniform mean temperature field.

52. EMERY, A. and CHU, N. C., "Heat Transfer Across Vertical Layers," J. of Heat Transfer, c 87, pp. 110-116 (1965).

Vertical surfaces were maintained at different constant temperatures. Various fluids giving a Prandtl number of from 3 to 30,000 were tested. Analytical approach considered boundary layer approximations coupled with integral techniques-solution very limited even though experiment and theory were reasonable close. An empircal equation is given that correlates the experimental results and contains the height to thickness ratio of the layer. This equation does not correspond to those given by other researchers.

53. ESHGHY, S., V. S. ARPACI, and J. A. CLARK, "The Effect of Longitudinal Oscillations on Fluid flow and Heat Transfer from Vertical Surfaces in Free Convection". Paper in preparation, also Tech. Report no. 1, DRA Project 05065, Univ. of Michigan, Ann Arbor, June, 1963.

54. FAND, R. M. and KAYE, J., "Influence of Sound on Free Convection from Horizontal Cylinder," ASME Trans. J. Heat Transfer, 83, Series C, no.2, pp. 133-48 (May 1961).

Reports resulted of flow visualization studies of flow field about horizontal heated cylinder for several sound pressure levels, frequencies and l/d ratios. Concludes that vortex motion begins to form in flow field at a "critical sound pressure level," and becomes fully developed at a higher SPL. Later paper by same authors contains essentially this information with improved discussion.

55. FAND, R. M. and J. KAYE, "Effects of High Intensity Stationary & Progressive Sound Fields on Free Convection from a Horizontal Cylinder," TN 59-18 (1959).

56. FAND, R. M. and J. KAYE, "The Influence of Vertical Vibration on Heat Transfer in Free Convection from a Horizontal Cylinder," Intern. Dev. in Heat Transfer, pp. 490-498, ASME (1961).

A 'critical' intensity of vibration (amplitude x frequency) was determined below which the influence of the vibration upon the heat transfer rate was negligible and above which the effect increased the heat flux significantly. This critical intensity was reported to be 0.3 ft./sec. Flow studies indicated that the significant rise in heat flux for intensities of vibration greater than 0.3 ft./sec. was due to vibrationally induced turbulence. The turbulence observed was not-- similar to that resulting from transverse vibration induced by a sound field. Empirical equations are presented for the heat flux. The general conclusions reached are that the effects of vibration upon the heat flux must be taken into account and that the direction of the vibration vector relative to the direction of the gravity force controls the basic character of the flow.

57. FAND, R.M. and J. KAYE, "Acoustic Streaming Near a Heated Cylinder," Journal of Acoustical Soc. of America, 32, p. 579 (1960).

This paper reports the results of an experimental investigation of the influence of intense acoustic vibrations on the rate of heat transfer from a circular cylinder to air in crossflow. An excellent review of the literature concerning the effects of vibrations, induced by sound fields and mechanically, on natural convection from a simple shape to an infinite atmosphere is given.

58. FAND, R. M. and J. KAYE, "The Influence of Sound on Free Convection from a Horizontal Cylinder," ASME Paper No. 60-HT-14.

59. FAND, R. M., "On the Mechanism of Interaction Between Vibrations and Heat Transfer," Wright Patterson AFB, Ohio Aeronautical Research Lab. Dec. 1961, 36p. ARL-148, Part IV.

60. FAND, R. M. and OTHERS, "The Influence of Sound on Heat Transfer from a Cylinder in Crossflow," Inter. J. of Heat and Mass Transfer, 5, July 1963, p. 571-596.

This paper reports the results of an experimental investigation of the influence of intense acoustic vibrations on the rate of heat transfer from a circular cylinder to air in crossflow. An excellent review of the literature concerning the effects of vibrations, induced by sound fields and mechanically, on natural convection from a simple shape to an infinite atmosphere is given.

61. FAND, R. M., "The Influence of Acoustical Vibrations on Convective Heat Transfer to Liquids," Office of Saline Water, Res. and Dev. Report No. 89, US dept. of Interior, PB181584 (1964).

62. FENSTER, S. K., VAN WYLEN, G. J. and J. A. CLARK, "Transient Pheomena Associated with the Pressurization of Liquid Nitrogen Boiling at Constant Heat Flux," Advances in Cryogenic Engng. 5, pp. 226-234.

63. FULTZ, D. and Y. NAKAGAWA, Proc. Roy. Soc. (London), A231, p. 211 (1955). (Experimental data is reported for Mercury contained in a rotating vessel heated from below).

64. GERSHUNI, G. Z., "On Free Convection in Space Between Vertical Coaxial Cylinders," (in Russian), Dokladi Akad, Nauk SSSR, N. S., 86, 4, pp. 698-699, (Oct. 1952).

65. GOODY, R. M., "The Influence of Radiative Transfer on Cellular Convection," J. Fluid Mechanics, 1, p. 424 (1956). (Free-convection studies in thin layers heated from below are reported.).

66. HAMMITT, F. G., "Heat and Mass Transfer in Closed, Vertical, Cylindrical Vessels with Internal Heat Sources for Homogeneous Reactors," PhD Thesis, Univ. of Mich. (Dec., 1957).

67. HAN, L. S., "Laminar Heat Transfer in Rectangular Channels," ASME Trans. J. Heat Transfer, 81, Series C, no. 2, pp. 121-128 (May, 1959).

68. HARDEN, D. G. and BOGGS, J. H., "Transient Flow Characteristics of Nat. Circulation Loop Operated in Critical Region," Heat Transfer and Fluid Mechanics Institute-Porc. Preprints for Meeting June 10-12, pp. 38-50 (1964).

69. HARJE, D. T., "Effect of Oscillating Flow on Heat Transfer in a Tube," Progress Report No. 20-362, JPL, Cal. Inst. of Tech. (Aug. 1958).

70. HARTNETT, J. P., W. E. WELCH and F. W. LARSEN, "Free Convection Heat Transfer to Water and Mercury in an Enclosed Cylindrical Tube," Nuclear Engng. and Science Conference, preprint 27, Session XX, Chicago (March 17-21, 1958).

71. HARTNETT, J. P. and W. E. WELCH, "Experimental Studies of Free Convection Heat Transfer in a Vertical Tube with Uniform Heat Flux," Trns.ASME, 79, p. 1961 (1957).

Heat transfer rates were determined for water in a vertical tube closed at the bottom, with a length-radius ratio of 21. This uniform wall heat flux case was found to agree on the average with the constant wall temperature case. The local Nusselt number was found to increase rapidly at a critical Rayleigh number. Below this critical value, the results agree with the values for a vertical flat palte with uniform heat input.

72. HEATON, H. S., W. C. REYNOLDS, and W. M. KAYE, "Heat Transfer in Annular Passages. Simultaneous development of velocity and temperature fields in laminar flow," International J. Heat Mass Transfer, 7, no. 7, pp. 763-781 (July, 1964).

73. HELLUMS, J. S., "Finite-Difference Computation of Natural Convection Flow," PhD Thesis, Univ. of Mich. (Sept. 1960).

74. HENSHAW, D. H. and D. F. DAW, "Design of Cold Temperature Probes," Nat. Aero. Establ. Cana. LR-184 (Jan. 1, 1954).

75. HOLMAN, J. P., H. E. GARTRELL AND F. E. SOEHNGEN, "A Study of Free Convection Boundary Layer Oscillations and Their Effects on Heat Transfer," WADC Tech. Report 59-3, Dec. 1959.

76. HOLMAN, J. P., and T. P. MOTT SMITH, "The Effects of High Constant Pressure Sound Fields on Free Convection Heat Transfer from a Horizontal Cylinder," WADC Tech. Note 58-352 ASTIA doc. no. 206906, Aero Res. Lab. (Dec, 1968).

77. HOLMAN, J. P., J. Heat Transfer, C 82, p. 393 (1960). Concerns a qualitative explanation of the change in heat transfer coefficients above a certain critical sound pressure.

78. HOLMAN, J. P., "The Mechanism of Sound Field Effects on Heat Transfer," J. of Heat Transfer, pp. 393-6 (Nov. 1960).

This paper attempts to explain the increase in heat transfer from a heated horizontal cylinder placed in a flow when a strong sound field is impressed on the flow, as the interaction of acoustical streaming with the boundary- layer flow.

It is noted here that at low sound intensity levels there is no effect on the heat transfer from the cylinder, whereas at high sound intensity levels there is an appreciable effect on the heat transfer from the cylinder. Several reasons are outlined in this paper to account for this increase in heat transfer.

79. ISAKOFF, S. E., "Analysis of Unsteady Flow Using Direct Electrical Analogs," Ind. and Eng. Chem., 47, no. 3, pp. 413-421 (March 1955).

80. IZUMI, R. "Natural Heat Convection Inside the Vertical Tube," Proc. 6th Japan Nat. Congr. Appl. Mech. Univ. of Kyoto, Japan, pp. 393-396 (Oct. 1956).

81. JACKSON, T. W., W. B. HARRISON and W. C. BOTELER,"Free Convection, Froced Convection, and Acoustic Vibrations in a Constant Temperature Vertical Tube,"Trans. ASME J. Heat Transfer, 81, Series C, 68 (1959).

This paper concerns free convection, forced convection and acoustic vibrations in a constant temperature vertical tube.

The results from this paper were compared with the results of a previous study of free and forced convection in a constant temperature vertical tube without acoustic vibrations in an attempt to determine the effect of acoustic vibrations on heat transfer.

One important result noted was a critical sound level of 118 decibels. Below 118 decibels there was little effect of the acoustic vibrations on the heat transfer coefficient. Above 118 decibels there was a considerable effect of sound on the heat transfer and free convection forces seemed to be negligible.

82. JACKSON, T. W., K. R. PURDY and C. C. OLIVER, "The Effects of Resonant Acoustic Vibrations on the Nusselt Numbers for a Constant Temperature Horizontal Tube," Intern. Dev. in Heat Transfer, Boulder, Colo. 1961 Part II, Sec. B, p. 483.

83. JOHNSON, N. R. and F. OSTERLE, "The Influence of Gradiant Temperature Fiedls on Thermocouple Measurements," ASME-AIChE Heat Trans. Conf., Univ. Park, Pa. Aig. 1957, Pap. 57-HT-18, 20pp.

84. JONES, C. D. and D. J. MASSON, "An Interferometric Study of Free-Convection Heat Transfer from Enclosed Isothermal Surfaces," Trans. ASME 77, 8, pp. 1275-1281 (Nov. 1955).

85. KAYS, W. M. and A. L. LONDON, "Convective Heat Transfer and Flow-Friction Behavior of Small Cylindrical Tubes--Circular and Rectangular Cross Sections," Trans. ASME, 74, 7, pp. 1179-1189 (Oct. 1952).

86. KESTIN, J., P.F. MARDER and H. E. WANG, "On Boundary Layers Associated with Oscillating Streams," Appl. Sci. Res. Section A., 10, no. 1 (1961).

87. KHLEBUTIN, G. N. and G. F. SHAILDUROV, "Heat Convection in a Vertical Annular Tube," (Russian) Inzhen. Fiz. Zh. 8, no. 1,pp. 3-7 (1965).

In this paper the natural convection of water and benzine ina vertical annular tube heated on one side and cooled on the other side is studied. It is stated that for constant temperature difference between the halves of the annulus, and circular motion of the liquid, that Nu=.125 Ra for Ra$<$16,000. This study confirms this equation experimentally. It is also stated that for cellular liquid motion the Nusselt number is a function of the radius of the annulus and increases with the Rayleigh number more slowly than the above equation indicates.

88. KRASSOLD, H., "Warmeabgabe Von Zylindrischen Flussigkeitschieten bei Naturlicker Konvektion," Frosch. Geb. Ingenieurw., 5, pp. 136-191 (1943).

An experimental study of natural convection between concentric cylinders. The gap between the cylinders was filled with water, transofmer oil, or machine oil. Three diameter ratios were utilized; the ratio varying from 1.234 to 3. Gap thicknesses were 7, 20, and 40 mm. Prandtl numbers ranged from 7 to 4000 while the Grashof number range was .1 to 10^8.

89. KRAUS, A. D., "Heat Flow Theory," Elec. Mfg., 63, no. 4 pp. 123-42 (Apr. 1959).

A general discussion and determination of the basic equations for conduction, convection and radiation heat transfer. Dimensional analysis is used to establish the parameters and various 'numbers' involved in convection heat transfer. Solution of several emperical equations is presented using simulated experimental data.

90. KREITH, F., L. G. ROBERTS, J. A. SULLIVAN and S. N. SINHA, "Convection Heat Transfer and Flow Phenomena of Rotating Spheres," Intern. J. of Heat and Mass Transfer, 6, no. 10 pp. 881-95 (Oct. 1963).

The flow about and the convection heat transfer to or from a rotating sphere were investigated experimentally and theoretically. For Prandtl numbers between 4.0 and 217 and Reynolds numbers below 5 x 10^4 the average Nusselt number for cooling as well as heating was found to be in reasonably good agreement with the result of a theoretical analysis based on a solution of the boundary-layer equations in which the boundary-layer thickness around the sphere was assumed to be uniform. A detailed study of the flow by means of a hot wire and several flow visualization techniques is discussed.

91. KUBANSKII, P. N., "Intesifikatiya Teploobemna Ultrazvukom," Teploenergetika, no. 11, pp. 79-83 (Nov. 1962). (Effect of high amplitude acoustic oscillations on convective heat transfer.)

92. KUDRIASHEV, L. I. and TKACHEV, IU. A., "Investigation of the Effect of Body Vibrations on the Heat Transfer Coefficients in Conditions of Free Convection," Issledovanic uliianiia vibratsii Tela na Koeffitsient teplootdachi v usloviakh svobodnoi knovektsii, Aviatsionnaia Teknika, 8, no. 1, p. 54-72 (1965). (in Russian).

93. LARSON, M. B. and A. L. LONDON, "Study of Effects of Ultrasonic Vibrations on Convective Heat Transfer to Liquids," ASME Paper 62-HT-44 for meeting August 5-8, 1962, p. 16.

94. LARSON, M. B., "Study of Effects of Ultrasonic Vibrations on Convective Heat Transfer in Liquids," Stanford University--Dept. of Mech. Engng. Tech. Report, 48, p. 102 (Sept. 30, 1960).

95. LARSEN, F. W. and J. P. HARTNETT, "Effect of Aspect Ratio and Tube Orientation on Free Convection Heat Transfer to Water and Mercury in Enclosed Circular Tubes," ASME Trans. J. Heat Transfer, 83, Series C, no. 1, pp. 87-93 (Feb. 1961).

The apparatus used in this study is a circular tube closed at the bottom and open to a cooled reservoir at the top with a constant uniform heat flux through the wall. This paper is principally concerned with the wall and fluid temperatures throughout the test section as a function of the heat input and the entering fluid temperature. It was found that for some cases the aspect ratio and tube orientation substantially affected the heat transfer.

96. LEE, B. H. and P. S. RICHARDSON, "Effect of Sound on Heat Transfer from a Horizontal Cylinder at Large Wavelengths," J. Mech. Engng. Sci, 7, no. 2, 127 (1965).

97. LEMLICH, ROBERT and M. A. RAO, "The Effect of Transverse Vibration on Free Convection from a Horizontal Cylinder," Int. J. Heat Mass Transfer, 8, p. 27-33.

This paper reports the results of an experimental investigation of the effect of vertical vibration on free convection from a small (0.049 inch diameter) constant temperature cylinder. The general trend of the results showed a substantial increase in the heat transfer rate, generally increasing with amplitude and with frequency. A correlation equation is presented which correlates the results of the present investigation and results of four other investigators.

98. LEMLICH, R. and H. W. HWU, "Effect of Acoustic Vibration on Forced Convective Heat Transfer," A. I. Chem. Engng. Journal, 7, no. 1, pp. 102-106 (Mar. 1961).

In this study sound at resonant and non resonant frequencies was imposed on the forced flow of air through a steam to air heat exchanger. It was found that the acoustic vibration improved the rate of forced convective heat transfer with increases in the Nusselt number of up to 51% being notes. The increases were seen to peak sharply at resonance. The results are correlated over most of the Reynold's number range investigated.

99. LEMLICH, R. and M. R. LEVY, "Effect of Vibration on Natural Convective Mass Transfer," Journal of American inst. Chem. Engngs., 7, pp. 240-242 (1961). Supporting data filed in Chem. Engng. Dept. of Univ. of Cincinnati, Cincinnati, Ohio.

100. LEMLICH, ROBERT, "Effect of Vibration on Natural Convective Heat Transfer," Industiral & Engng. Chem., 47, no. 6, pp. 1175-1180 (1955).

This paper reports the results of an experimental investigation of the effect of both vertical and horizontal vibration of heated wires. No discernable differences between the effects on the heat transfer rate for the different vibratory didections was found. This result is questionable. Empirical correlations are presented which represents the data with acceptable deviations. The net effect of the vibration was to increase the heat transfer rate, the actual increase being a function of amplitude and frequency. The author attempts to explain his results in terms of a 'stretched' film. Experimental apparatus oversimplified, resulting in questionable results.

101. LEMLICH, R., "Vibration and Pulsation Boost Heat Transfer," Chem. Engng., 68, pp. 171-176 (1961).

102. LEVY, S., "Integral Methods in Natural Convection Flow," ASME Paper No. 55, APM 22.

This paper presents an evaluation of the range of application, accuracy, and usefulness of integral methods in natural-convection flow. The governing equations are set up for a body of arbitrary shape and large curvature maintained at a constant temperature. Boundary-layer approximations are applied. Specific cases are solved and compared with experimental results where available. Very complete discussion of the integral method.

103. LEVY, J. J., Journal of Applied Mech., 22, p. 515 (1955). (Obtains solutions for free convection flows in enclosed tubes using the integral method).

104. LIGHTHILL, M. J., "Theoretical Consideration Free Convection in Tubes," Quart. J. Mech. and Appl. Math., 6, pp. 398-439 (1953).

Methods are presented for predicting the flow and heat transfer due to free convection in heated vertical tubes, closed at the bottom and opening into a reservoir of cool fluid at the top.

105. LIGHTHILL, M. J., "The Response of Laminar Skin Friction and Heat Transfer to Fluctuations in Stream Velocity," Proc. of Royal Soc., Series A,224 p. 23 (1954).

106. LIN, C. C., "Motion of the Boundary Layer with a Rapidly Oscillating External Flow," Proc. 9th Intern. Congr. of Appl. Mech., 4, 1957.

107. LINKE, W., "Warmeubergang bei pulsierender Stromung," Zeit. des VDI, Bd, 95, p. 1179 (1953).

108. LIU, C. Y, W. K. MUELLER, and F. LANDIS, "Natural Convection heat Transfer in Long Horizontal Cylindrical Annuli," Inter. Dev. in Heat Transfer, Part V, pp. 976-984, Amer. Soc. Mech. Engrs., New York (1961).

109. LORD RAYLEIGH, "Theory of Sound," 1st American Edition (1st Ed. 1877) II, Dover Pub. New York, 1945, App. A.

110. MARKHAM, J. J., "Second-Order Acoustic Fields: Streaming with Viscosity and Relaxation," The Physical Review, 86, no. 4, pp. 497-502 (Mar 15,1952).

111. MARTINELLI, R. C., L. M. K. BOELTER, E. B. WEINBERG, and S. YAKAHI, "Heat Transfer to a Fluid Flowing Periodically at Low Frequencies in a Vertical Tube," Trans. ASME, 65, pp. 789-798 (1943).

112. MARTINELLI, R. C. and M. K. BOELTER, "The Effect of Vibration on Heat Transfer by Free Convection from a Horizontal Cylinder," Proc. 5th Int. Cong. Appl. Mech., p. 578 (1938).

113. MARTINI, W. R. and CHURCHILL, S. W., "Natural Convection Inside a Horizontal Circular Cylinder," AIChE, Journal, 6, p. 251 (1960).

This paper concerns the natural convection flow of air in a horizontal cylinder with the vertical halves of the cylinder being held at different constant temperatures. Pictures of the flow are presented along with plots of the data, which consists chiefly of temperature and velocity measurements.

114. MAWARDI, O.K., "On Acoustic Boundary-Layer Heating," Jour. of the Acous. Soc. of America, 26, no. 5, pp. 726-231 (Sept. 1954).

115. MEDWIN, H., "An Acoustic Streaming experiment in Gases," Jour. of the Acous. Soc. of America, 26, no. 3, pp. 332=341 (May 1954).

116. MELDAHL, A., "The Heat Transfer Coefficient for Fluids in Laminar Movement," Engng., 169, 4398, p. 541 (May 1950).

117. MERTE, H., JR. and CLARK, J. A., "Pool Boiling in Accelerating System," ASME Trans. J. Heat Transfer, 83, no. 3 pp. 233-42 (Aug. 1961).

118. MIKULIN, E. I., "Temperaturnoe pole dvokh tverdykh tel rzdelennkh zazorom," Inzhereno fizicheskii zhrnal, 4, no. 2, pp. 52-7 (Feb. 1961). (Analytical solution of temperature distribution in 2 concentrically located cylinders of finite length separated by gap, when heating (cooling) begins at end of cylinders).

119. MINORSKY, N., "Self-Excited Oscillations in Dynamical Systems Possessing Retarded Actions," Jour. of Applied Math., 9, no. 2, A65-271 (1942).

120. MORGAN, P. G., "Effect of Vibration and Pulsation on Heat Transfer," Engng. & Boiler House Rev., 78, no. 4, pp. 128-129 (Apr. 1963).

121. MORKOVIN, M. V., "On Eddy Diffusivity Qusi-Similarity and Diffusion Experiments in Turbulent Boundary Layers," Int. J. Heat Mass Transfer, 8 no. 1, p. 129 (1965).

122. MORSE, PHILIP M., "Plane Waves of Sound," Vibration & Sound, second Edition pp. 217-229 (energy in a plane wave).

123. MURAKAWA, K., "Heat Transfer by Free Convection in closed Vertical Pipes with Annular Spacing," (in Japanese) Trans. Japan Soc. Mech. Engrs., 20, pp. 100, 797-802 (1954).

124. MYATT, D. O., ET AL, "Pulsatory and Vibrational Phenomena," Ind. and Eng. Chem., 47, no. 6, pp. 1142-1164 (June 1955).

125. NAKAGAWA, Y., Proc. Roy. Soc. (London), A240, p. 108(1957). (Free convection studies in this layers heated from below are reported.)

126. NAKAGAWA, Y., "Heat Transport by Convection," Physics of Fluids, 3, no.1 pp. 82-6 (Jan. Feb. 1960).

127. NANDA, R. S. and V. P. SHARMA, "Free Convection Laminar Boundary Layers Oscillating Flow," J. of Fluid Mech., 15, part 3, pp. 419-428 (1963).

128. NEELY, D. F., "Effect of vibration on Heat Transfer from Cylinders in Free Convection," MS Thesis, Aug. 1964, 77 GA/ME/64-2 AD-61-173, N65027290, Air Force Inst. of Tech. Wright-Patterson AFB, Ohio.

129. NYBORG, W. L., "Acoustic Streaming due to Attenuated Plane Waves," J. of the Acous. Soc. of America, 25, no. 1, pp. 68-75 (1953).

130. OSTRACH, S. and P. R. THORNTON, Trans. ASME, 80, 363 (1958). Free Conv. to fluids confined in vertical tubes closed at the bottom with the side walls having a linear temperature distribution has been analyzed, using an integral method. The resulting velocity and temperature distribution are presented.

131. OSTRACH, S. and P. R. THORNTON, "On the Stagnation of Natural Convection Flows in Closed End Tubes," ASME Paper no. 57-SA-2.

132. OSTRACH, S., Trans. ASME, 79, p. 299 (1957). (Free Convection studies in this layers from below are reported).

133. OSTRACH, S., "An Analysis of Laminar Free-Convection Flow and Heat Transfer about a Flat Plate Parallel to the Direction of the Generating Body Force," Naca Report 1111, 1953.

134. OSTROMOV, G. A., "Free Convection Under the Conditions of Internal Probelm," Naca TM-1407.

135. PELLEW, A. and R. V. SOUTHWELL, "On Maintained Convection Motion in a Fluid Heated From Beloc," Proc. Roy Soc., A, 176, 312 (1940).

A theoretical investigation of the stability in a viscous fluid contained between a lower horizontal surface which isheated and an upper horizontal surface which is cooled. Uniform and constant temperatures are assumed for each of the horizontal surfaces but the fluid at each surface may be either free or in contract with rigid surfaces preventing slip. The shape of the 'cells' formed is not specified but is allowed to vary through the use of a parameter.

136. PERKINS, H. C., JR. and G. LEPPERT, "Local Heat Transfer Coefficients on Uniformly Heated Cylinder," Intern. Journal of Heat and Mass Transfer, 7, pp. 153-158 (1964).

Local heat transfer coefficients are determined for water in cross flow over a uniformly heated cylinder. Channel blockage is also investigated with a correction for the effect of blockage on the heat transfer being presented.

137. PERSEN, L. N., "A Simplified Approach to the Influence of Gortler-type Vortices on the Heat-transfer from a Wall," ARL 65-88, Office of Aerospace Research, U. S. Air Force, Wright-Patterson AFB, Ohio (1965).

138. PFEEFER, R., "Heat and Mass Transport in Multiparticle Systems," I & EC Fundamentals, 3, no. 4, 380 (1964).

139. PIERRE, C. ST and C. TIEN, "Experimental Investigation of Natural Convection Heat Transfer in Confined Space for Non-Newtonian Fluid," Can. J. Chem. ENGNG, 41, no. 3, pp. 122-7 (June 1963).

140. POOTS, G., "Heat Transfer by Laminar Free Convection in Enclosed Plane Gas Layers," Quart. J. of Mech. and Appl. Math., 11, pp. 257-273 (1958).

141. PREDVODITELEV, A. S., "O Khanktere Teplovogo Dvizheniya V Zhidkostyakh," Ihzhereno-Fizicheskii Ahurnal, 4, no. 6, 7, 8, pp. 3-19 (June 1961).

142. RANEY, W. P., J. C. CORELLI and P. J. WESTERVELT, "Acoustic Streaming in the Vicinity of a Cylinder," Jour. of the Acous. Soc. of America, 26, no. 6, pp. 1006=1017 (1954).

143. RICHARDS, R. J., W. G. STEWARD and R. B. JACKOBS, "Survey of Literature of Heat Transfer from Solid Surfaces to Cryogenic Fluids," U. S. Bur. Standrd. NBS Tech. Note no. 122, p. 44 (Oct. 1961).

144. ROMONOV, A. G., "Study of Heat Exchange in a Dead End channel Under Free Convection Conditions," Izvestiva Akademii Nau, USSR, Otdeleni Teknishes Kikh, no. 6, pp. 63-79 (1956).

145. ROBINSON, A. R., "The Symmetric State of a Rotating Fluid Differentially Heated in the Horizontal," J. Fluid Mech., 6, p. 599 (1959). concerns the motion of a fluid inside a rotating annulus or square cross section. The side walls are held at different constant temperatures.

146. ROUND, G. F., NEWTON, R. and REDBERGER, P. J., "Variable Mesh Size in Iteration Methods of Solving Partial Differential Equations and Appl. to Heat Transfer," Chem. Engng. Progress Symposium, 58, no. 37, pp. 29-42 (1962).

147. RUSS, R. N. and R. S. RUSS, "Effect of Vibration on Heat Transfer from Cylinders in Free Convection," MS Thesis, Aug. 1962, 86 p. GA/ME/62-4, AD-292335, N64-80527, Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

148. SCANLAN, J. A., "Effects of Normal Surface Vibration on Laminar Forced Convective Heat Transfer," Indus. & Engng. Chem, 50, no. 10, pp. 1565-8 (Oct. 1958).

149. SCHLICHTING, H., "Berechung ebener Periodischer Grenzschictstromungen," Phys. zs. 33, p. 327 (1932).

The boundary-layer flow is calculated in the vicinity of a wall for the case where the potential flow is a periodic function of time. The differential equations are integrated through the use of successive approximations. The problem is also studied for the case of flow about an oscillating cylinder.

150. SCHMIDT, E., Chem. Eng. Tech. 28, 175 (1956). Free-convection in a confined space between two parallel plates.

151. SCHMIDT, R. and W. VON BECKMAN, "Das Temperatur-und Gaschwindigketsfeld vor einer warme abegbenden senkrechten Platte bei Naturiicher Konvektion," Technischi Mechanik und Thermodynamik, 1, pp. 341-349, 391-406 (1930).

152. SCHOENAHALS, R. J. and J. A. CLARK, "Laminar Free Convection Boundary-Layer Perturbations Due to Transverse Wall Vibration," J. Heat Transfer, C 84, 225 (1962). A perturbation solution of the boundary-layer equations was made to determine the effect of vibration on heat transfer from a heated vertical plate.

153. SCHOENHALS, R. J., "The Response of Laminar Incompressible Fluid Flow and Heat Transfer to Transverse Wall Vibrations," PhD thesis Univ. of Mich., Jan. 1961, ASME Paper No. 63-WA-123.

154. SCHOENHALS, P. J. and J. A. CLARK, "Laminar Free Convection Boundary-Layer Pertubation Due to Transverse Wall Vibrations" Trans. Amer. Soc. Mech. Engngs. Series C, J. of Heat Transfer, 86, 2, pp. 159-165, May 1964.

This is an analytical solution for the case of a heated vertical wall, vibrated parallel to itself. The solution requires some questionable assumptions, such as 'the bulk of the fluid is at rest with respect to the vibrating wall'. The boundary layer equations for an incompressible fluid are solved by pertubation technique to yield velocity and temperature distributions. The techniques used are valuable and, if more realistic assumptions were used, the results might be more valid.

155. SEIGEL, R. and R. H. NORRIS. "Test of Free Convection in a Partially Enclosed Space Between Two Heated Vertical Plates," ASME Paper no. 56-SA-5, Trans. ASME 79, 663 (1957).

156, SHAILDUROV, G. F., "Convective Heat Transfer in Horizontal Cylinder," Int. J. Heat & Mass Transfer V. 2, no. 4, pp. 280-2 (June 1961).

157. SHINE, A. J., "Effect of Transverse Vibrations on Heat Transfer Rate from Heated Vertical Plate in Free Convection," ASME Paper no. 58-HT-27, for meeting Aug. 9-12, 1959, p. 8.

158. SLAVONOVA, E. I. "Ob Yasheistoi Strukture Konvektivnogo Potoka Zhidkosti V Vertikal'nom Tsilindre Kruglogo Secheniya," Inzhereno-Fizicheskii Zhurnal, 4, no. 8, pp. 80-6 (Aug. 1961). Cellular Structure of Convection Flow in Vertical Cylinder of Round Cross Section.

159. SOROKIN, V. S., "Steady Motion of a Fluid Heated From Below," (in Russian) Prikl. Mat. Melsh., 18, 2, 197-204 (Mar/Apr. 1954).

160. SPARROW, E. N. and S. J. KAUFMANN, "Visual Study of Free Convection in a Narrow Vertical Enclosure," NACA RM E55 L, 14-a (Feb. 1956).

This describes an experimental effort which was performed to check the reported inferrment of the existance of alternate upflow and downflow regions in a thin annulus containing liquid sodium. S. & K. use vertical slots (height/width = 50), containing distilled water, which are cooled from above by copper tape strips and exposed to a heated reservoir from below. They conclude that (from shadowgraph studies) "no flow pattern was found to be steady with time" . . . ."The dominating characteristics of the flow patterns were instability and change.

161. SPROTT, A. L., HOLMAN, J. P. and DURAND, F. L., "Experimental Study of Effects of Strong Progressive Sound Fields on Free-Convection Heat Transfer from Horizontal Cylinder," ASME-Paper 60-HT-19 for meeting Aug. 15-17, 1960 p. 12.

162. SPURLOCK, J. M., T. W. JACKSON, K. R. PURDY, C. V. OLIVER and H. L. JOHNSON, "The Effects of Resonant Acoustic Vibrations on Heat Transfer to Air in Horizontal Tubes," WADE Tech. Note 59-330 (June 1959).

163. ST. PIERRE, CARL and CHI TIEN, "Experimental Investigation of Natural Conv. Heat Transfer in Confined Space for Non-Newtonian Fluid," The Canadian J. of Chem. Engng., pp. 122-127 (June, 1963).

Correlates experimental data for horizontal flat plates heated from bottom with Non-newtonian fluid between plates. Determines Nusselt number as function of Rayleigh and Prandtl numbers, and a 'flow behavior index' N which is supposed to account for deviation of fluid from Newtonian behavior.

164. STRAUMANN, W., "Ein Instationaeres Verfahren Zur Messung Der Waermeleitfaehigkeit Von Fluessigkeiten und Gasen," Schweizer Archiv, 27, no. 7 pp. 290-304 (July 1961).

165. SZEBEHELY, V. G., "Generalization of the Dimensionless Frequency Parameter in Unsteady Flows," Report no. 833, David W. Taylor Model Basin, Wash., (Nov. 1952).

166. TACHIBANA, F., S. FUKUI, and H. MITSUMRA, "Heat Transfer in Annulus with Inner Rotating Cylinder," Japan Soc. Mech. Enggns., 3, 9, pp. 119-23 (Feb. 1960).

167. TAYLOR, R. D. and J. G. DASH, Phys. Rev., 106, 398 (1957).

168. TELEKI, C., R. M. FAND, and J. KAYE, "Influence of Vertical Vibrations on the Rate of Heat Transfer from a Horizontal Cylinder in Air," Wright Air Dev. Command, T.N. 59-357 (1960).

169. TIMO, D. P. "Free Convection in Narrow Vertical Sodium Annuli," KAPL-1082, Knolls Atomic Power Lab., General Electric Co. Mar. 5, 1954 (Contract No. W-31-109 Eng. 52).

170. TRILLING, L. "On Thermally Induced Sound Fields," Jour. of the Acous. Soc. of America, 27, no. 3, pp. 423-431 (May 1955).

171. WATSON, W. J., "Effect of Vibration on Heat Transfer from Cylinders Vibrated Sinusoidally within a Vertical Plane in Free Convection," MS Thesis 1964, p. 58 GAW/ME/65-3, AD-623617, CFSTI, N66-14210 Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

172. WEINBAUM, S., "Natural Convection in Horizontal Circular Cylinder," J. of Fluid Mech., 18, 3, pp. 409-37 (Mar. 64).

This paper presents a theoretical analysis of steady, two-dimensional convective motion induced in a horizontal circular cylinder whose wall is non-uniformly heated (the wall is maintained at a sinusoidally-distributed temperature). The problem is analyzed for various values of the phase angle and magnitudes of the Rayleigh number (low versus high).

173. WEST, F. B. and A. T. TAYLOR, "The Effect of Pulsations on Heat Transfer," Chem. Engng. Progr., 48, no. 39 (1952).

174. WESTERVELT, P. J., "Effect of Sound Waves on Heat Transfer," Acoustical Soc. America J., 32, 3, pp. 337-8 (Mar. 1960).

Short note suggesting that sound waves begin to affect heat transfer when fluid particle displacement due to sound exceeds thickness of acoustic boundary layer.

175. WESTERVELT, P. J., "Hydrodynamic Flow and Oseen's Approximations," J. Acoustical Soc. of America, 25, p. 951 (1953).

176. WHITT, F. R., "Film Heat-Transfer Coefficients in Vessel Jackets," Brit. Chem Engng., 6, 8, pp. 533-7 (Aug. 1961).

177. WICK, R. S., "An Analysis of Oscillatory Flow in Liquid-Propellant Rocket Systems and the Application of the Analysis to Combustion Stability," Report no. 20-231, JPL, Pasadena, August 10, 1954.

178. WILKES, J. O. and S.W. CHURCHILL, "The Finite Difference Computation of Natural Convection in a rectangular Enclosure," Preprint 10d, 57th Annual Meeting Amer. Inst. Chem. Engrs., Boston (1964).

The authors present plots of stream function and temperature, obtained by finite difference methods, for the motion of a fluid in a long horizontal enclosure of rectangular cross-section with one vertical side heated and the other cooled; two-dimensional motion is assumed. The transient problem is considered. Heat transfer results are given in terms of mean Nusselt numbers. Complete details of the numerical methods used are given in J. O. Wilkes PhD thesis, Univ. of Michigan (1963).

179. WILLIAMS, J. E. F., "The Noise of High-speed Missiles", Random Vibration, 2, pp. 147-176.

180. YAMAGA, J., "Effects of Sounds and Vibrations on Convective Heat Transfer," J. Japan Soc. Mech. Engrs., 65, no. 525, p. 1415 (1962).

181. YANG, W. J. and H. C. YEH, "Unsteady Boundary-layers on Vibrating Spheres in a Uniform Stream," Physics of Fluids, 8, p. 806-811 (May 1965).

181a. BROOKS, R. V., "Free Convection Velocity Measurements by the Use of Neutral Density Particles," Thesis, Georgia Institute of Technology (1965).

TRANSPORT PROPERTY DETERMINATION AND THE EFFECTS OF VIBRATIONS ON PROPERTIES

182. ABE, A. and P. J. FLORY, "The Thermodynamic Properties of Mixtures of Small, Nonpolar Molecules," J. Am Chem. Soc., 87, no. 9, 1838 (1965).

183. BEN-NAIM, A., "On the Difference Between the Thermodynamic Behavior of Argon in D_2O and H_2O," J. Chem. Phys., 42, no. 5, 1512 (1965).

184. BONDI, A., "On the Thermal Conductivity of Liquids and Polymers and its Relation to the Pressure Coefficient of Viscosity," J. Chem. Phys., 19, no. 1, pp. 128-129 (Jan. 1951).

185. BORN, M. and H. S. GREEN, "A General Kinetic Theory of Liquids," Cambridge Press, Cambridge, England (1949).

186. BRYNGDAHL, O., "Accurate Determination of Coefficients of Thermal Conductivity in Liquids with the Aid of a Shear-interferometric Method," (in German) Ark. Phys., 21, no. 22, p. 289 (1962).

Thermal conductivities were measured for water, alchol, glycerol, and castor oil using an optical shear-interferometric method. Detailed description given explaining the method used and the design of experimental equipment. Results claimed accurate to 0.5 percent.

187. CHALLONER, A. R. and OTHERS, Proc. Roy. Soc. (London), 245, 259 (1958). Concerns measurement of thermal conductivity in liquids.

188. CHANDRA NAD V. S. KANDA, "Thermodynamic Properties of He^3 and He^4 solutions," II temperatures above the superfluid transition in solution, Phys. Fluids, 7, no. 1, 7 (1964).

189. CODEGONE, C., "Thermal Conductivity Measurements to 180C," Italian, Thrmotecnica, 4, pp. 573-574 (Dec. 1950).

190. COLLINS, D. J., R. GREIF and A. E. BRYSON, JR., "Measurements of the Thermal Conductivity of Helium in the Temperature Range 1600-6700°K," Int. J. Heat Mass Transfer, 8, no. 9, 1290 (1965).

191. CONNOLY, J. H., "Combined effect of Shear Viscosity Thermal Conduction, and Thermal Relaxation on Acoustic Propagation in Linear-Molecule Ideal Gases," J. Acoust. Soc. Am. 36, no. 12, 2374 (1964).

192. CUTLER, M. and G. T. CHENEY, "Heat Wave Methods for the Measurement of Thermal Diffusivity,' J. Appl. Phys., 34, no. 7, p. 1902 (1963).

193. DAUPHINEE, T. M., D. K. C. MACDONALD and W. B. PEARSON, "The Use of Thermocouples for Measuring Temperatures below 70°K. A new type of low temperature Thermocouple," J. Sci. Instrum. 80, no. 1, 11, pp. 399-400 (Nov., 1953).

194. EISEEL, K. M. and A. C. H. HALLETT, "The Viscosity of Liquid Helium at Frequencies of 11.3 kc/sec and 35.5 kc/sec," Proc. of 5th Intern. on Low Temperature Physics & Chem. Univ. of Wisconson Press(1958).

195. ENGLEHARDT, A. G. and A. V. PHELPS, "Transport Coefficients and Cross Sections in Argon and Hydrogen-Argon Mixtures," Physical Rev., 133, no. 1A, A 375 (1964).

196. EPSTEIN, M., "A Model of the Boltzmann Collision Integral for Mixtures of Light and Heavy Particles," Rept. No. TDR-469 (5240-20)-9, Aerodynamics and Propulsion Research Lab., Laboratory Operations, Aerospace Corp. El Segundo, Calif. (1965).

197. GAYLORD, E. W. and OTHERS, "On the Theoretical Analysis of a Dynamic Thermocouple," Trans. ASME, 80, p. 307 (1958).

A theoretical analysis of a thermocouple used to measure the contact temperature between two moving dissimilar metals. Of no value to our research.

198. HALPERN, C. and R. J. MOFFAT, Nat. Bur. Stand. Monogr. 27 (1961).

A bibliography on recent works concerned with temperature measurement.

199. HARPER, J. C., "Coaxial Cylinder Viscometer for Non-Newtonian Fluids," Rev. Sci. Instrum., 32, p. 425 (1961).

A description of a narrow gapped coaxial cylinder viacometer which is particularly designed for application to non-Newtonian fluids. Complete description of the instrument. Instrument has several features which make it a highly desirable general purpose research device.

200. HARRISON, E. F., "Intermolecular-force Effects on the Thermodynamic Properties of Helium with application," AIAA J., 2, no. 10, 1854 (1964).

201. HECHT, C. E., "Classical Equation of State for Molecular Interacting with Purely Repulsive Potentials," J. Chem. Phys., 42, no. 8, 2862 (1965).

202. HEIKKILA, W. J. and A. C. H. HALLETT, "The Viscosity of Liquid Helium II," Can. Jour. Phys., 33, p. 420 (1955).

Rotating cylinder viscosimeter was used to measure viscosity of liquid He II. Data Compared with results of oscillating disc method viscosity measurements. Method limited to fluid velocities of 0.08 cm/sec.

203. HERZBERT, F., "Effective Density of Boiling Liquid Oxygen," Advances in Cryogenic Engng., 5.

204. HIRSCHFELDER, J. D., C. F. CURTISS, and R. B. BIRD, "Molecular Theory of Gases and Liquids," John Wiley, New York.

205. HOLSEN, J. N. and M. R. STRUNK, "Binary Diffusion Coefficients in Nonpolar Gases," I & EC, Fundamentals, 3, no. 2, 143 (1964).

206. HURLE, I. R., "On the Thermal Energy Transfer between Free Electrons and Molecular Vibration," J. Chem. Phys., 41, no. 11, 3592 (1964).

207. HUST, J. G. and A. L. GOSMAN, "Functions for the Calculation of Entropy, Enthalpy, and Internal Energy for Real Fluids using Equations of State and Specific Heats," NASA CR-55325; NBS-R-301, Cryogenic engng. Lab. Nat. Bureau of Stand. Boulder Colo. (1963).

208. IOFFEE, A. V. and A. F. IOFFEE, "Simple Method of Measuring Thermal Conductivity," (in Russian) Zh. Tech. Fiz., 22, no. 12, pp. 2005-2013 (dec. 52).

209. KALIDAS, R. and G. S. LADDHA, "Viscosity of Ternary Liquid Mixtures," J. Chem. Engng. Data 9, No. 1, 142 (1964).

210. KARPLUS, M. H., J. KOLKER, "Van Der Walls Forces in Atoms and Molecules,' J. Chem. Phys., 41, no. 12, 3955 (1964).

211. MASON, H. L, "Thermal Conductivity of Some Industrial Liquids from 0 to 100 C," ASME Annual Meeting, N.Y. Paper 53-A-50, pp. 4 (Dec. 1953).

212. MAUDE, A. D., Brit. J. Appl. Phys. 12,292 (1961). An investigation of the end effects in falling-sphere viscometers are studied.

213. MIZUSHIMA, S., "Thermal Conductivity of Crystals and Liquids," J. Phys. Soc. Japan, 9, 4, 546-552 (July/Aug. 1954).

214. REED, R. D. and D. HENDERSON, "Cell Model for Quantum Fluids. II Thermodynamic Properties of Liquid H ," J. Chem. Phys. 41, no. 9, 2704 (1964).

This is a continuation of a previous paper by the authors (Cell Model for Quantum Fluids II). The earlier procedure was revised to include a more reasonable correction factor to the WKB energy levels and the properties of liquid H_2 were calculated.

215. REED, T. M. III and M. D. MCKINLEY, "Estimation of Lennard-Jones Potential Energy Parameters from Liquid Densities," J. Chem. Engng. Data, 9, no. 4, 553 (1964).

216. ROTHE, C. F., "Simple Surface Thermometer," Rev. Sci. Instr. 29, 436 (1958).

Describes the use of a thermistor and VTVOM to measure surface temperatures.

217. SCHROCK, V. E. and E. S. STARKMAN, Rev. Sci. Instr. 29, 625 (1958). Concerns the measurement of the thermal conductivity of liquids.

Describes the construction of the spherical apparatus in detail. Describes an experimental procedure for estimating the effect of convection on the results. Accuracy of ± 2% in data is claimed.

218. SPARROW, E. M. and J. L. GREGG, "The Variable Fluid Property," ASME Paper No. 57-A-46.

219. STOW, R. W., "Rapid High-Sensitivity Recording Thermometer," Rev. Sci. Instr., 29, 774 (1958).

This describes the use of a hypodermic-mounted thermistor and associate circuitry for continuous recording of subcutaneous temperatures.

220. VAN ITTERBEEK, A. and J. NIHOUL, "Measurements of Thermal Diffusion in H-He Mixtures by Using Ultrasonics," Acustica, 5, 2, 142-145 (1955).

221. VULMAN, F. A. and V. P. VORONINA, "The Calculation of Thermodynamic Properties of Water and Water Vapour on a High-speed Computer Using the Zagoruchenko-Kazavchinsky Equation," Teploenergetika No. 6, 64 (1964).

222. WALDMANN, L., "The Basic Kinetic Equations for Par-Ortho-hydrogen Mixtures," Physics, 30, no. 1, 17 (1964).

223. WEINBAUM, S., "Entropy Boundary Layers," Research Rept. 207, Avco Corp, Evertt Mass. (1965).

224. WIDMER, F., Kaltetechnik, 14, 38 (1962). For liquids, a system using a transient heat input to an immersed wire has been used to obtain thermal conductivities of several refrigerants.

225. WOOLF, J. R. and W. L. SIBBITT, "Thermal Conductivity of Liquids," Inst. Engng. Chem., 46, 9, pp. 1947-1952 (Sept. 1954).

The authors used concentric brass cylinders to experimentally evaluate the thermal conductivities of 13 different liquids. Thermistors were used to measure temperatures and changes in temperature of 0.002°F were said to be detectable. The effect of radiation was neglected. The authors sighted data obtained in Purdue Lab supporting the neglection of radiation. The work of Mull & Richer, Beckmond, and Jakob was used to estimate the effects of convection. the maximum error due to gas bubbles and sample purity was estimated to be 2.5%. The thermal conductivities were displayed in graphical and tabular form. The data obtained was compared with the results of others when possible. However, the author listed only the data points with measurement errors of less than 5 %. The experimental procedure and apparatus used seem suitable for experimentation involving vibrations.

APPENDIX II

TEST CELL CONFIGURATION POSSIBILITIES

APPENDIX II

Test Cell Configuration possibilities
(dimensions in inches)

H	D	W	H/W	D/W
4	22	4.414	0.906	4.984
4	23	3.867	1.034	5.948
4	24	3.365	1.189	7.131
4	25	2.904	1.377	8.609
4	26	2.478	1.614	10.493
4	27	2.083	1.920	12.960
4	28	1.717	2.233	16.307
4	29	1.376	2.907	21.076
4	30	1.058	3.782	28.364
6	16	3.365	1.783	4.754
6	17	2.687	2.222	6.328
6	18	2.083	2.880	8.640
6	19	1.544	3.887	12.810
6	20	1.058	5.673	18.909
6	21	0.618	9.707	33.973
6	22	0.219	24.456	100.672
8	13	2.478	3.229	5.247
8	14	1.717	4.659	8.154
8	15	1.058	7.564	14.182
8	16	0.481	16.640	33.280
10	11	1.897	5.272	5.799
10	12	1.058	9.455	11.345
10	13	0.348	28.766	37.396
12	8	2.083	5.760	4.320
12	9	1.058	11.345	9.455
12	10	0.219	54.912	50.336
14	8	1.717	8.154	4.659
14	9	0.618	22.649	14.560
16	7	1.717	9.318	4.077
16	8	0.481	33.280	16.640
18	7	0.618	29.120	11.324
20	6	1.058	18.909	5.673
22	6	0.219	100.672	27.456
24	5	1.058	22.691	4.727